

Plug-in Hybrid Electric Vehicles

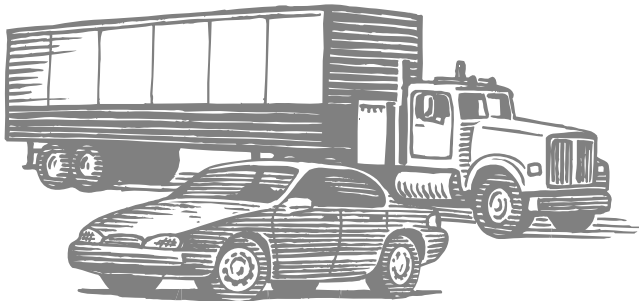
Current Status, Long-Term Prospects and Key Challenges

Presented at Clean Cities Congress and Expo
by

Tony Markel

National Renewable Energy Laboratory

May 8th, 2006



With support from the
U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
FreedomCAR and Vehicle Technologies Program



Disclaimer and Government License

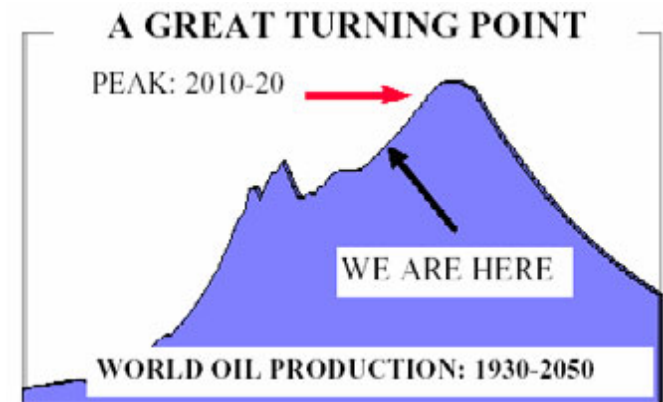
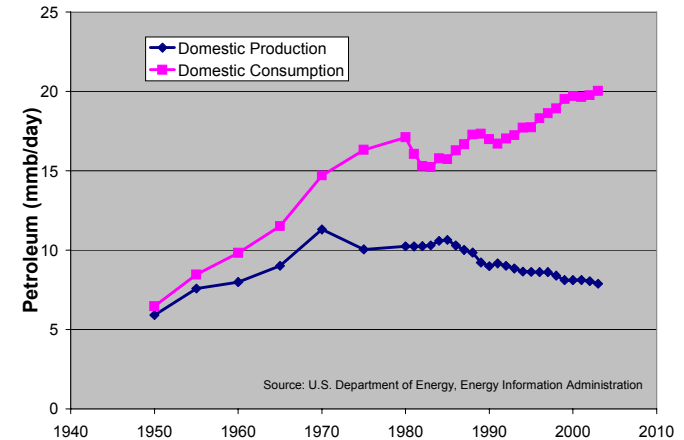
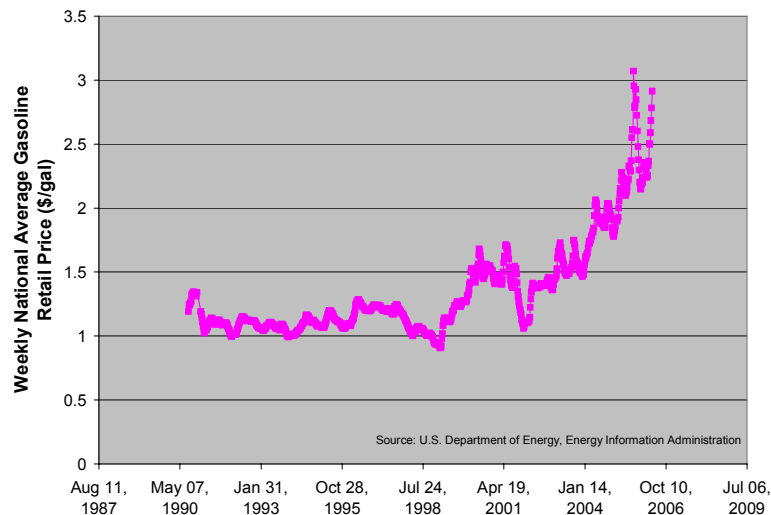
This work has been authored by Midwest Research Institute (MRI) under Contract No. DE-AC36-99GO10337 with the U.S. Department of Energy (the “DOE”). The United States Government (the “Government”) retains and the publisher, by accepting the work for publication, acknowledges that the Government retains a non-exclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for Government purposes.

Neither MRI, the DOE, the Government, nor any other agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe any privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not constitute or imply its endorsement, recommendation, or favoring by the Government or any agency thereof. The views and opinions of the authors and/or presenters expressed herein do not necessarily state or reflect those of MRI, the DOE, the Government, or any agency thereof.

The Perfect Storm

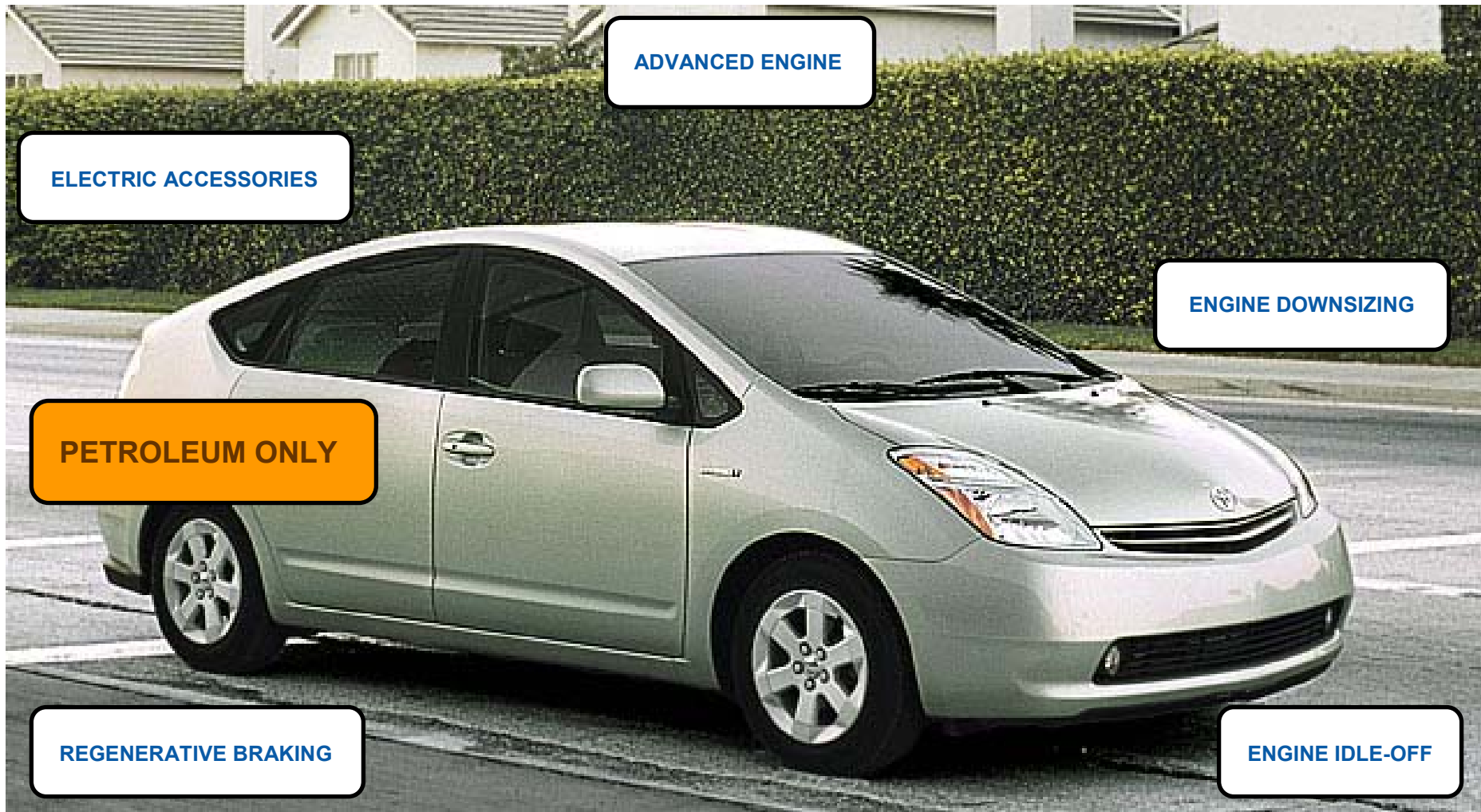
- Petroleum **consumption** has steadily **increased** while domestic **production** has continued to **decline**
- World oil **production** predicted to **peak** within the next 5-15 years
- Recent increase in **gasoline price** is indicator of **growing tension** between supply and demand

Gasoline price - 85% rise in 5 years!



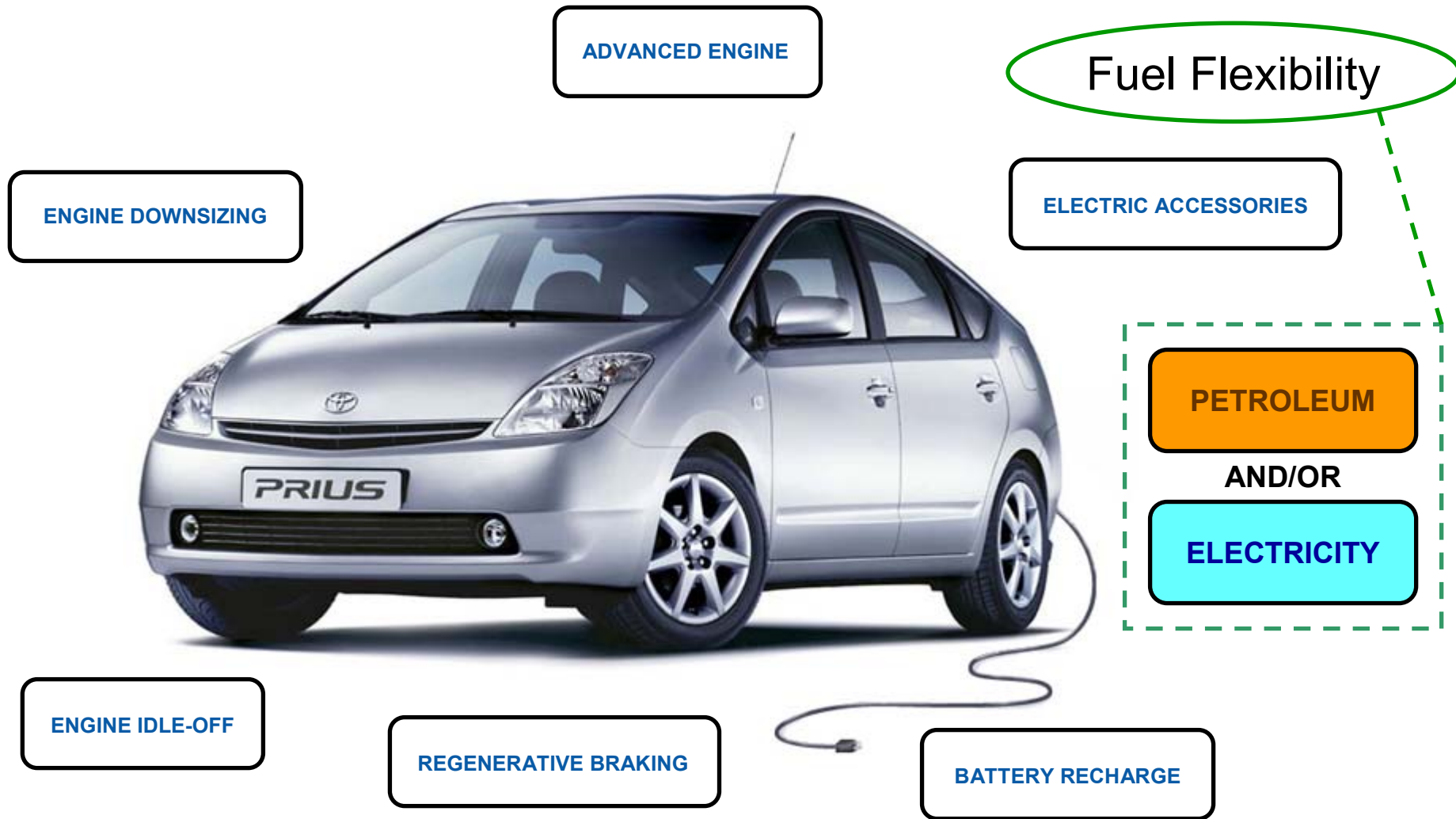
WHAT'S OUR PLAN?

A “Full” Hybrid



76hp gasoline engine, 67hp electric motor, 1.5kWh battery

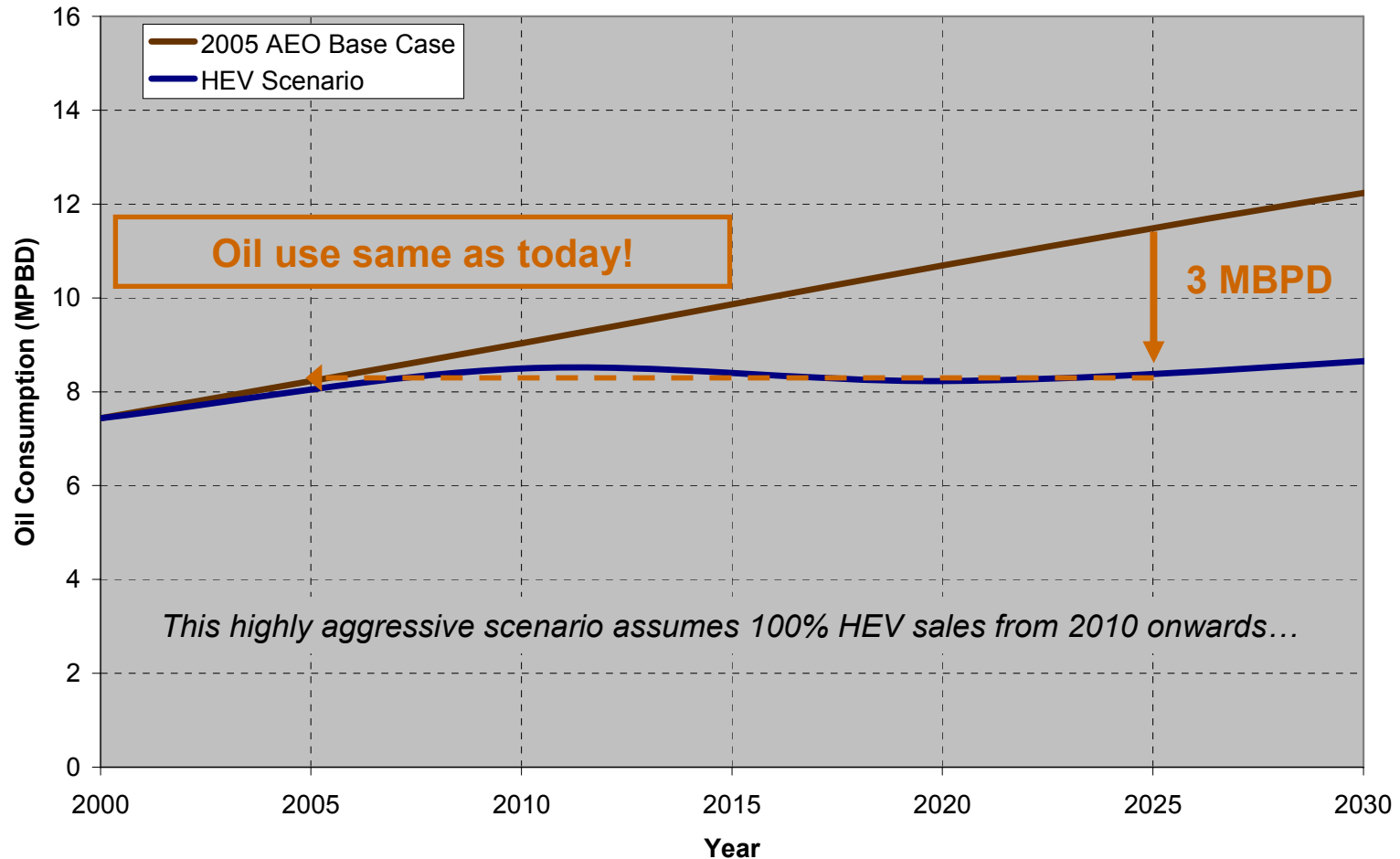
A Plug-In Hybrid



76hp gasoline engine, 67hp electric motor, 9.0kWh battery (30mi)

Oil Use Reduction with HEVs

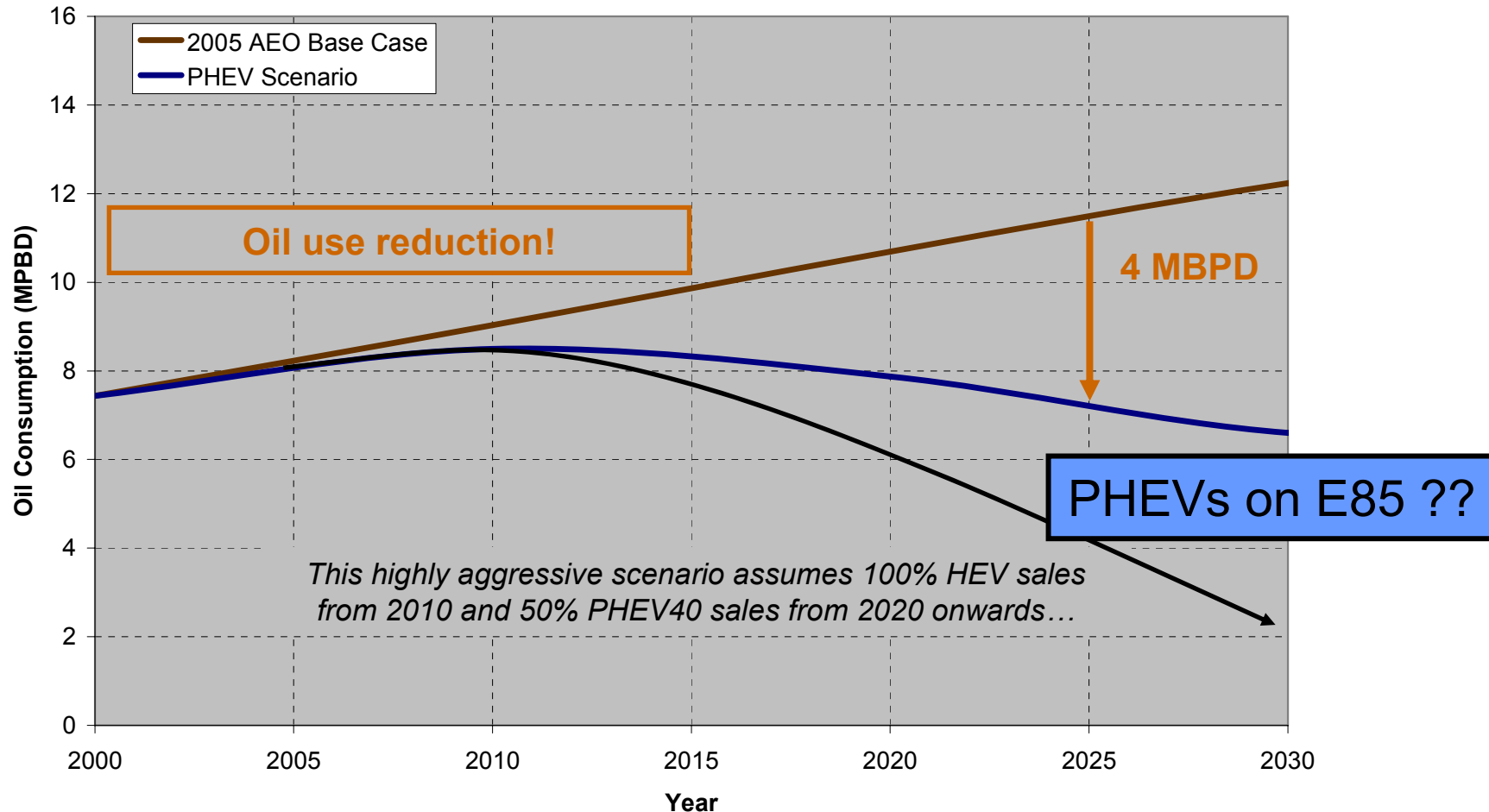
Light Duty Fleet Oil Use - Impact of HEVs on Consumption



HEVs unable to reduce consumption below today's consumption level

Oil Use Reduction with PHEVs

Light Duty Fleet Oil Use - Impact of PHEVs on Consumption



PHEVs reduce oil consumption with a transition to electricity

OEM Plug-In Hybrids



2003 Renault Kangoo Elect'road

- up to 50mi electric range
- approximately 500 sold in Europe



DaimlerChrysler Sprinter PHEV

- 15 prototypes being produced for testing in various locations in Europe and North America
- up to 20mi electric range

Other PHEV Prototypes - Industry



EnergyCS Plug-In Prius



HyMotion Escape PHEV



AFS Trinity Extreme Hybrid™



AC Propulsion Jetta PHEV

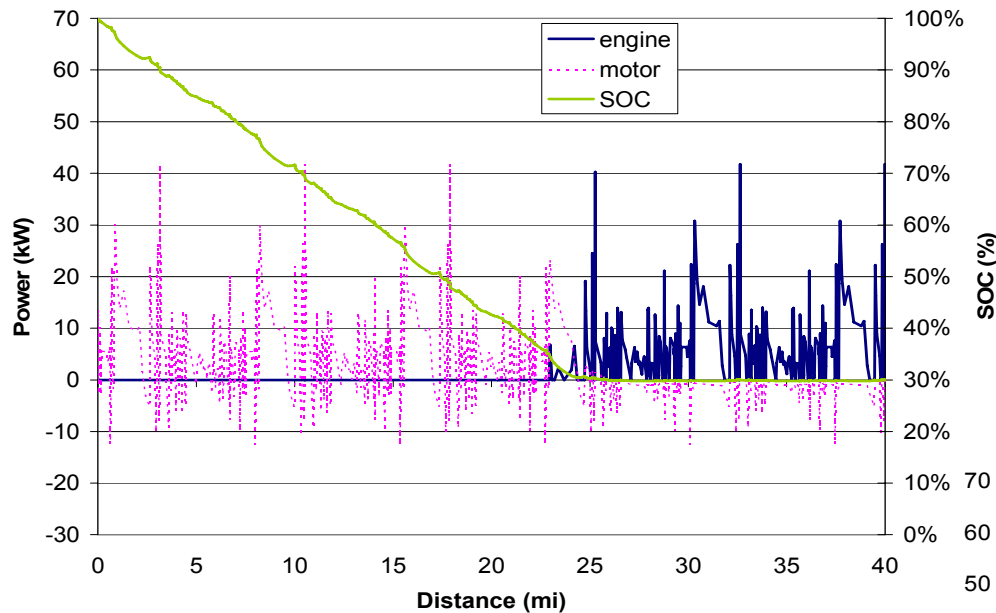


Esoro AG H301

Design Options

All-Electric vs Blended Strategy

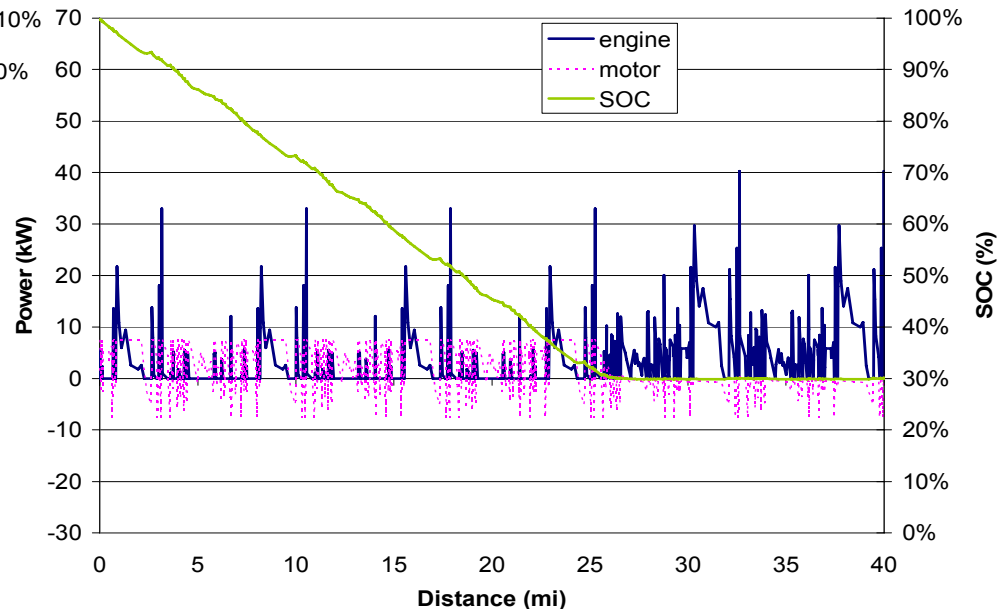
All-Electric



- Engine turns on when battery reaches low state of charge
- Requires high power battery and motor

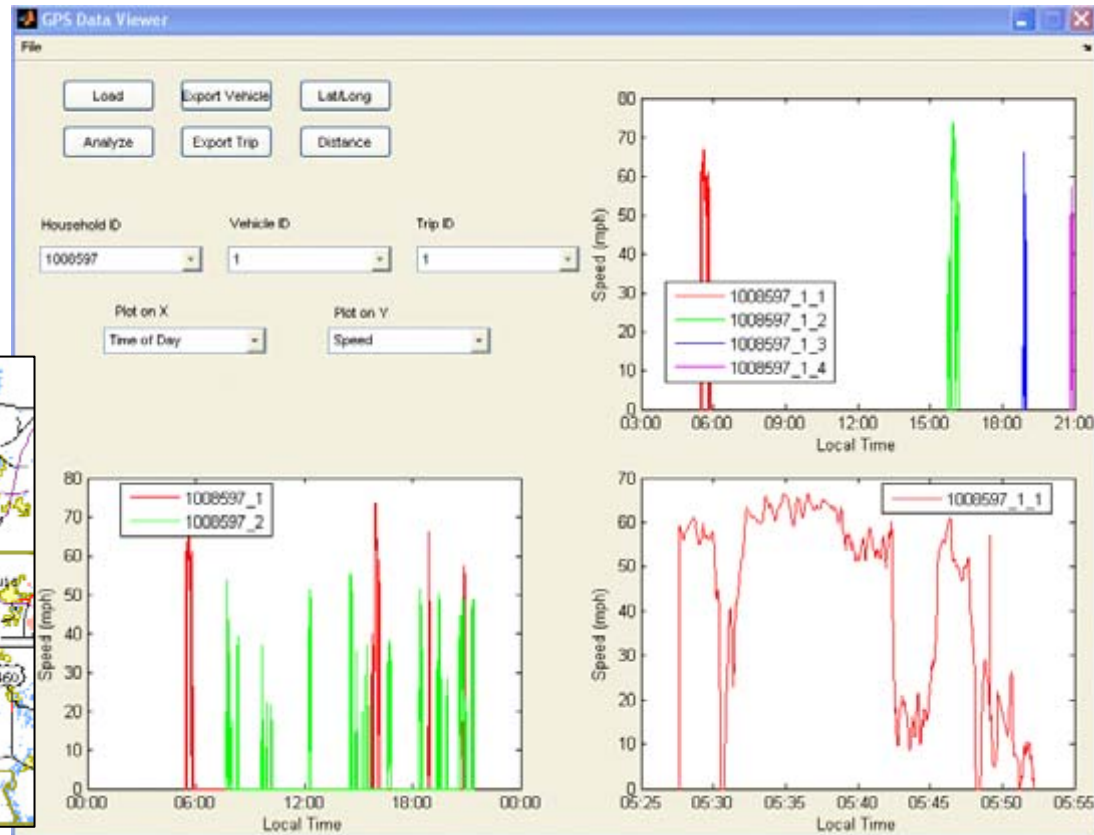
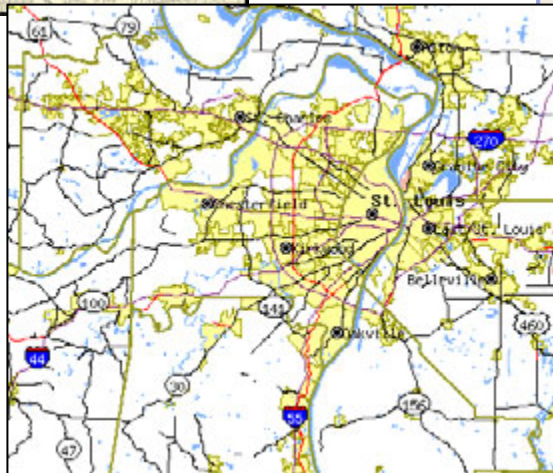
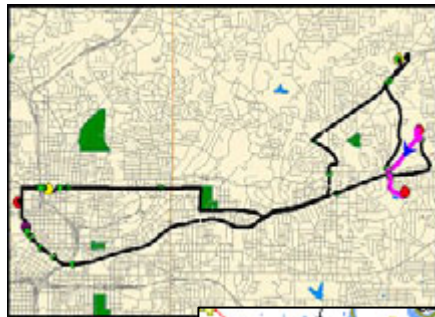
- Engine turns on when power exceeds battery power capability
- Engine only provides load that exceeds battery power capability

Blended



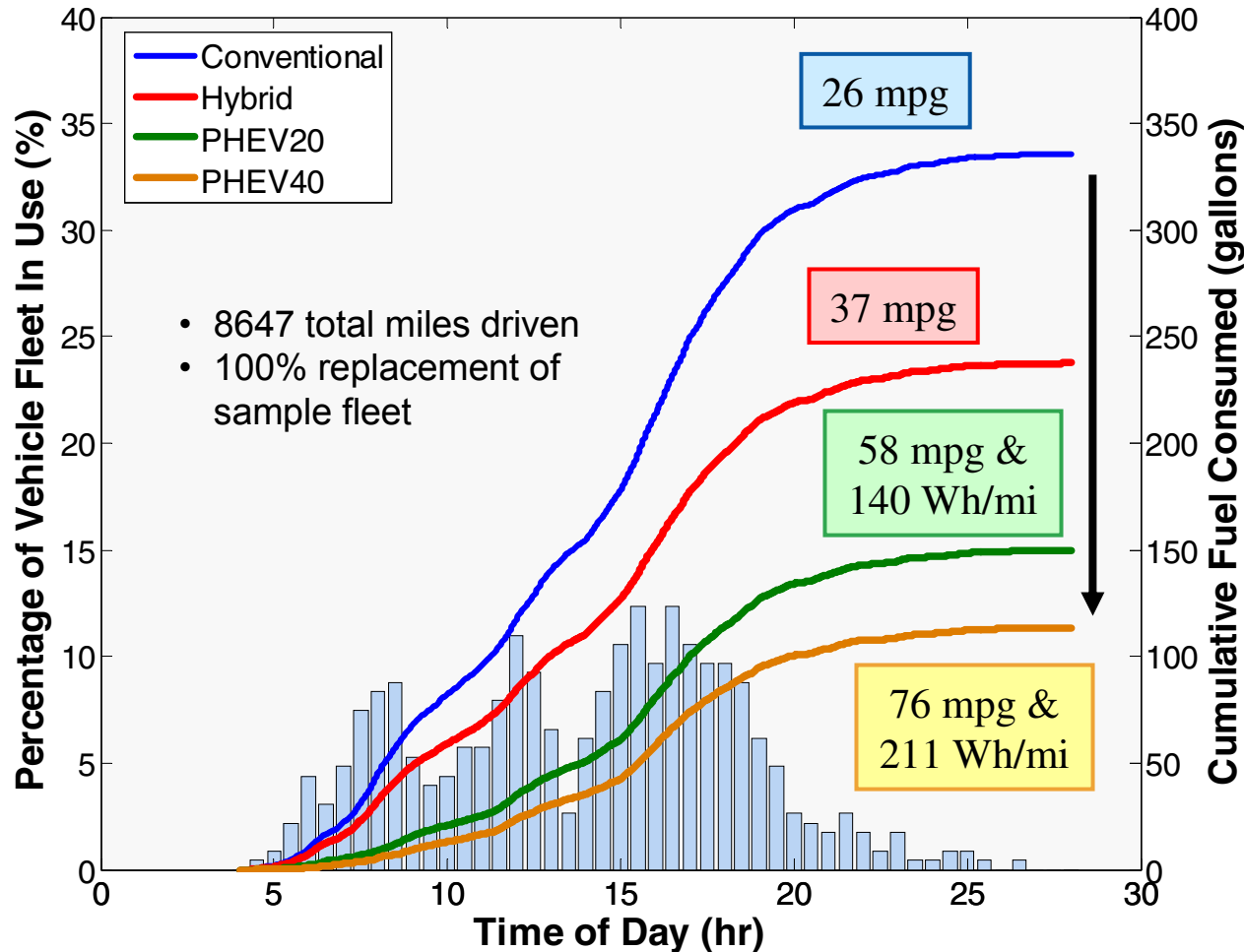
Household Travel Survey Data Can be Used to Predict Real-World Benefits of Advanced Technologies

- Provides valuable insight into travel behavior
- GPS augmented surveys supply details needed for vehicle simulation



PHEVs Reduce Fuel Consumption By 50% On Real-World Driving Cycles

227 vehicles from St. Louis each modeled as a conventional, hybrid and PHEV



	Average Daily Costs		
	Gas.	Elec.	¢/mi
CV	\$3.15	---	8.3
HEV	\$2.21	---	5.8
PHEV20	\$1.41	\$0.48	5.0
PHEV40	\$1.08	\$0.72	4.7

Assumes \$2.15/gal and 9¢/kWh

PHEVs:
~40% reduction in
operating costs
~\$460 annual savings

HEVs and PHEVs Likely to Reduce Greenhouse Emissions

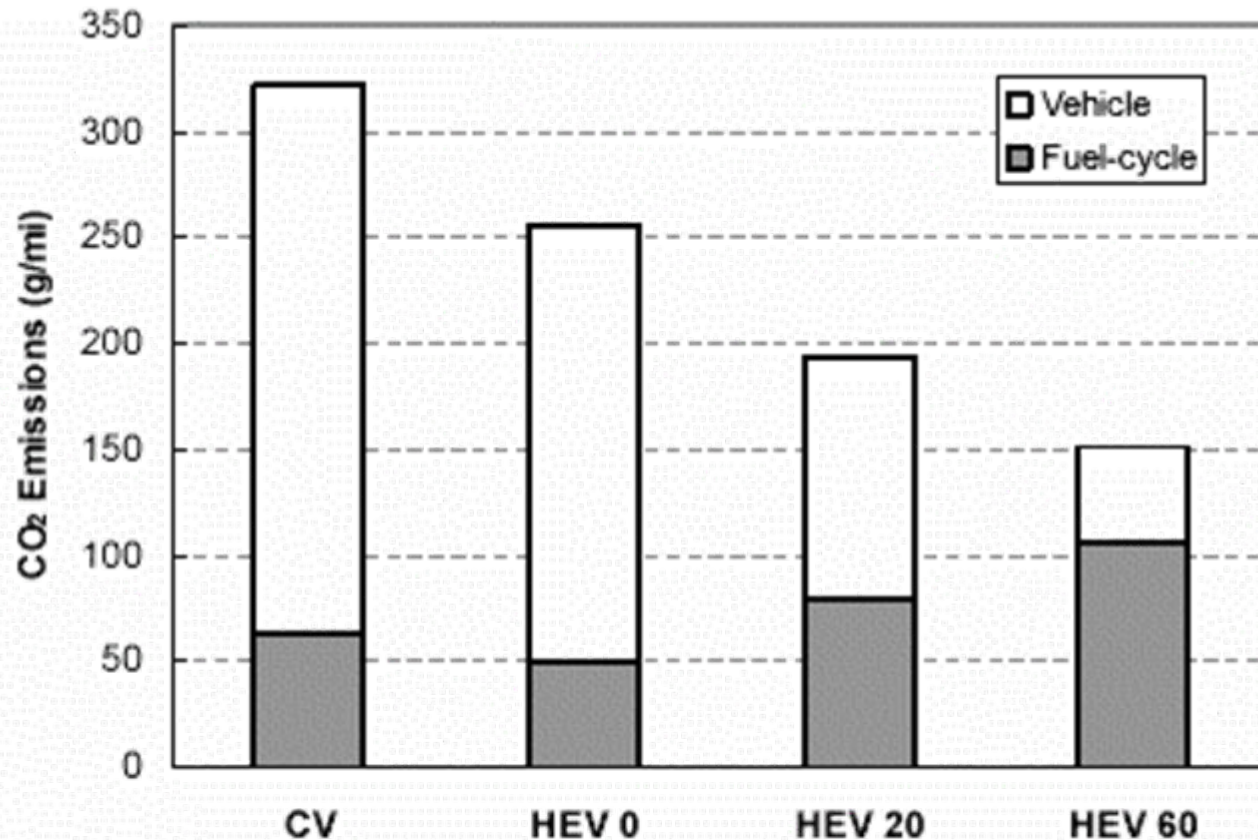


Figure 2-10
Greenhouse Gas Emissions (CO₂) “Well-to-Wheels” for the Compact Car for the Average Driving Schedule and Charging Nightly

Electrified Miles May Lead to Cleaner Operation

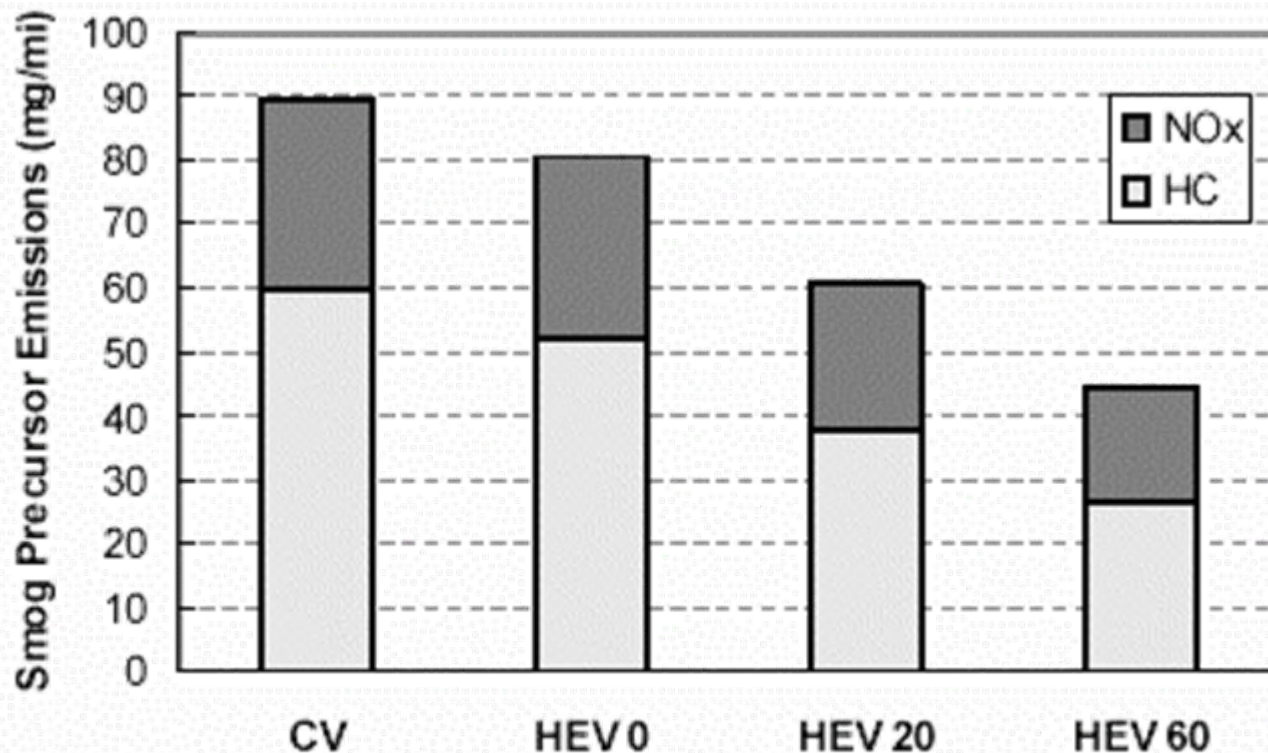
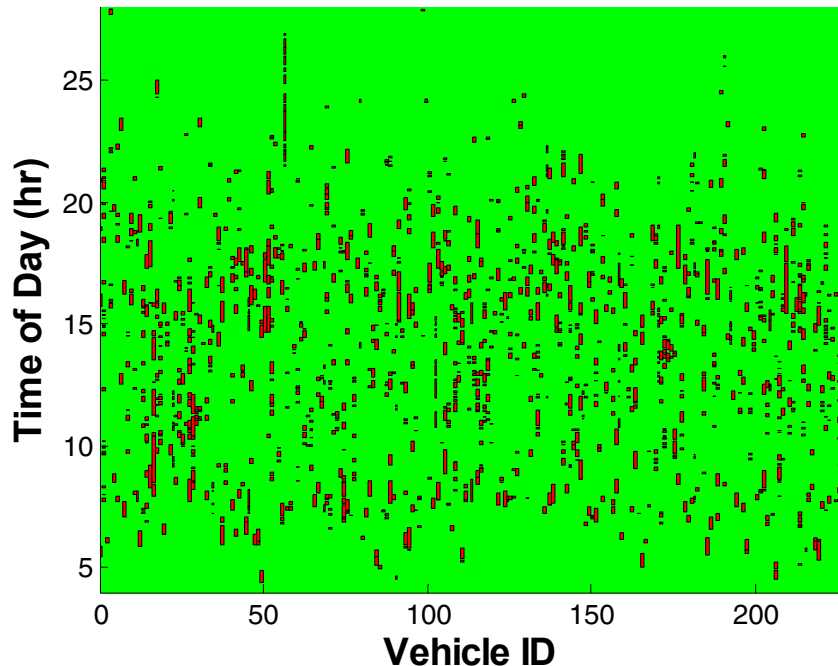


Figure 2-7
NOx Plus HC (Smog) “Well-to-Wheels” Emissions for the Compact Car for the Average Driving Schedule and Charging Nightly

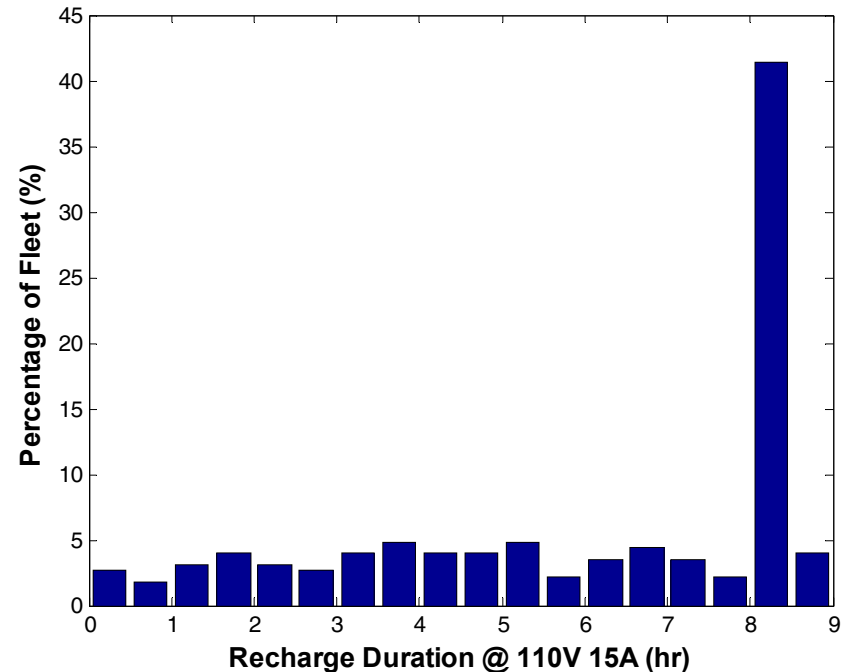
In-Use Simulations Show Reasonable Recharge Times with Standard Household Outlet

- Typical vehicle is used less than 5% of the time
 - Lots of opportunity for recharging
- Both PHEV20 and PHEV40 owners likely to get full recharge overnight with standard outlet

Vehicle In-Use (red)



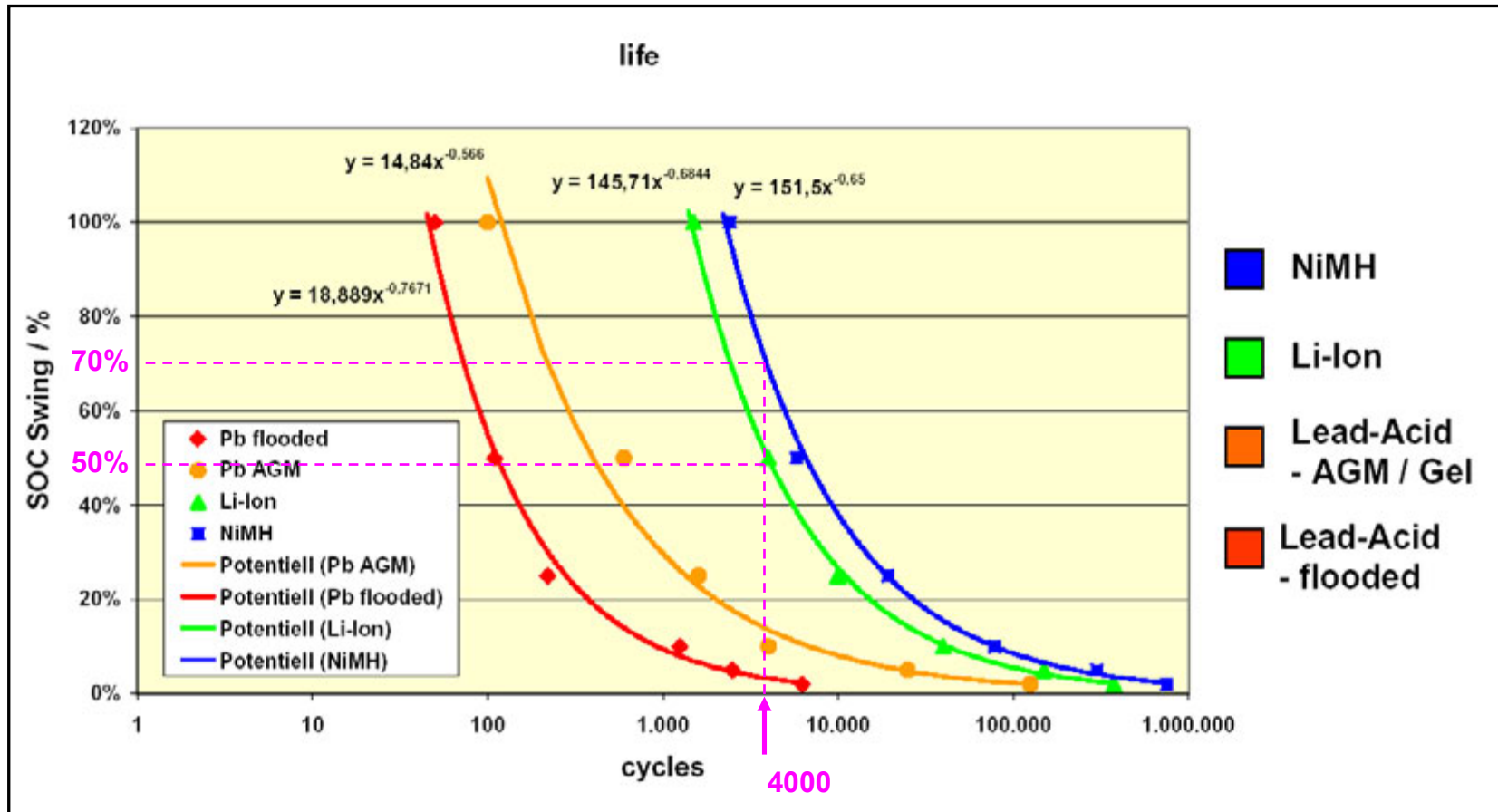
PHEV40



Technical Challenges

Battery Life

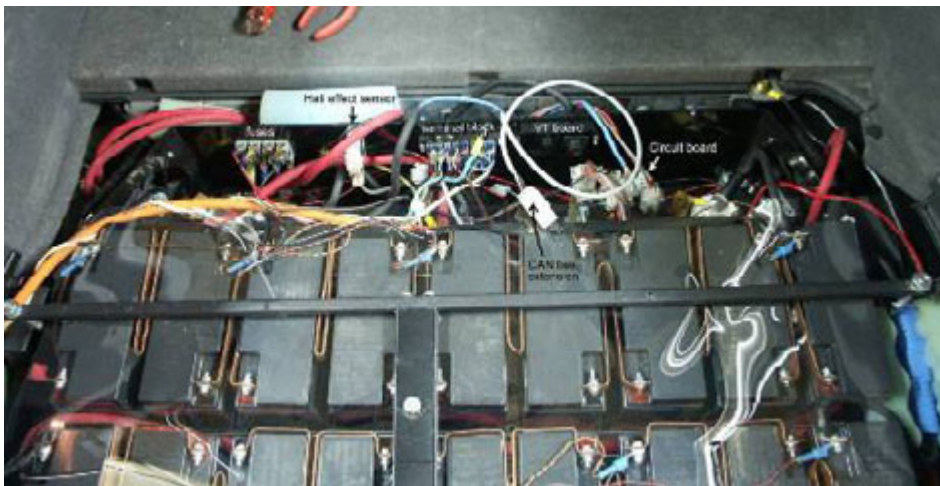
- PHEV battery likely to deep-cycle each day driven: 15 yrs equates to 4000-5000 deep cycles
- Also need to consider combination of high and low frequency cycling



Data presented by Christian Rosenkranz (Johnson Controls) at EVS 20

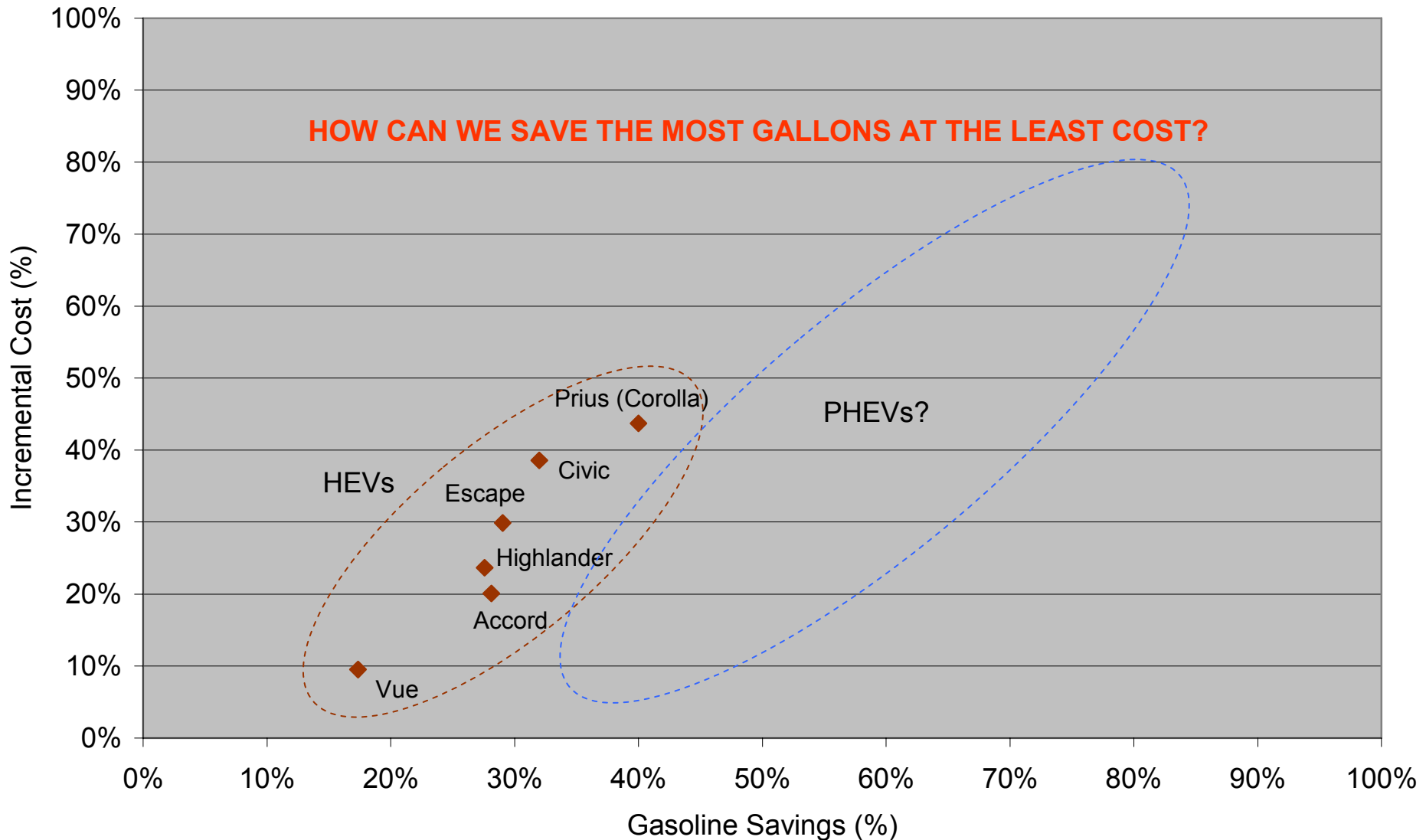
Technical Challenges

Battery Packaging



Technical Challenges

Vehicle Costs



- Plug-in hybrid technology uses electricity from the utility grid to reduce petroleum consumption beyond that of HEV technology
 - Predicted 50% reduction in in-use consumption based on simulations using travel survey data
- Industry interest is growing and some prototypes have been built
 - Collaboration between labs and industry will likely lead to innovative systems solutions
- The U.S. Department of Energy is expanding its research portfolio to include PHEVs
 - Research will address key remaining barriers to commercial PHEVs including battery life, packaging, and cost